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16. ABSTRACT This research study was initiated to re-evaluate compaction control procedures for cement treated base and to investigate new and revised methods. Laboratory and field investigations substantiated that the existing laboratory compaction procedures were causing unrealistically high maximum density determinations for some aggregates. Revisions to the test procedure resulted in a decrease in the maximum density of most problem materials without significantly changing the maximum densities of materials which were found to be relatively easy to compact on the street. The possibility of using a control strip for determining maximum density was investigated. This technique has potential as a satisfactory control method but would not eliminate the need for a laboratory standard unless the types of compaction equipment used for the construction of the control strip are rigorously specified. A statistical analysis of moisture-density determinations with nuclear gages indicated that cement treated aggregates could be tested with about the same accuracy as untreated aggregates.					
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TRANSPORTATION LABORATORY

January 1975

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TL No. 633399

Mr. R. J. Datel
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final
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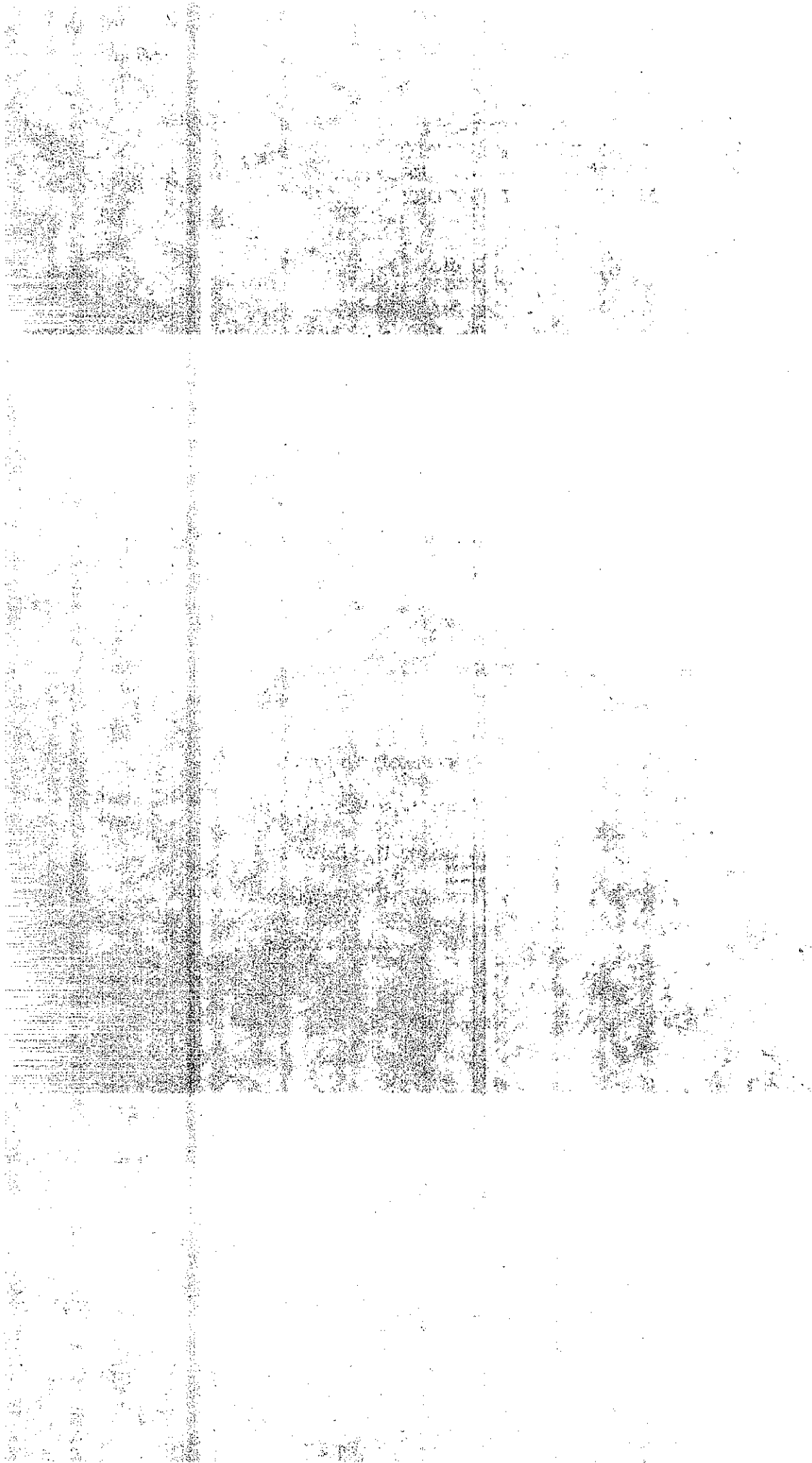
COMPACTION CONTROL OF
CEMENT TREATED BASE

Study made by Pavement Branch
Under the Supervision of John B. Skog
Principal Investigator Robert N. Doty
Co-Investigator Max L. Alexander
Report Prepared by Max L. Alexander

Very truly yours,


JOHN L. BEATON
Chief Engineer
Office of Transportation Laboratory

Attachment



ACKNOWLEDGEMENTS

This is the final report for a study titled "Compaction Control of Cement Treated Base" which was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

This project was begun under the supervision of Ernest Zube and principal investigator Clyde G. Gates. The laboratory and field testing were conducted under the direction of Donald L. Durr. Much of the data analysis and interpretation were also completed by Donald L. Durr.

The authors wish to express their appreciation to the construction personnel of the various highway districts and to the contractors who cooperated by performing extra work in conjunction with the field studies. Acknowledgment is also given to Harvey Sterner, Duane Andersen and Jack Knott who conducted most of the laboratory and field tests.

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Test Method No. Calif. 312-E, April 7, 1969 "Design and Testing of Classes "A" and "B" Cement Treated Bases".	

INTRODUCTION

The use of cement treated bases (CTB) in the construction of California highways had its beginning in the late 1930's. Along with the use of cement treated aggregates came the need for suitable test procedures to determine proper proportions of aggregate, cement and water and to assure satisfactory spreading and compaction of the treated materials.

In 1940 the Materials and Research Department developed a laboratory method[1] for the preparation of test specimens of cement treated materials. This procedure was the forerunner of Test Method No. Calif. 312[2] which is still used for mix design and compaction control of CTB in California. The sand volume test, which is used to determine in-place densities of compacted materials, was also developed during this same period of time. Since their inception, the instructions for performing these tests have been rewritten several times but the basic equipment and procedures have remained essentially unchanged.

Through the years satisfactory contract control of CTB has been maintained with the prescribed procedures. A comparison of the in-place densities of construction audit cores in 1963 with the maximum densities determined by Test Method No. Calif. 312 showed that the compaction specification for CTB was being met reasonably well in most cases. The study included 261 field cores from 19 projects. Ninety percent of the cores had densities equivalent to at least 95% of the average laboratory test densities for the individual projects (i.e., a relative compaction at least 95%). Ninety-seven percent of the cores had a relative compaction of 93% or more.

During the 1967 construction season complaints began to arise, from contractors and State construction inspection personnel alike, regarding the use of the existing compaction control procedures. The major sources of dissatisfaction arose from a trend toward increasing difficulty in attaining 95 percent relative compaction and the inability to take relatively economical corrective measures because of the time lag between placement of the CTB and determination of relative compaction.

The primary objective of this study was to identify the causes of the difficulties being encountered in achieving the specified compaction since no real problems had been previously encountered. The second objective was to revise or develop a new testing procedure to overcome the field problems.

It was determined relatively early in this study that most of the problem of achieving the required field densities could be traced to unrealistic maximum (laboratory) densities for certain aggregate sources. These aggregates were soft and angular and in the existing laboratory test were broken and squeezed together in a way that was not duplicated during field compaction. Therefore three new approaches for the determination of the test maximum density of CTB were investigated. The first was a modification of the laboratory compaction procedure contained in Test Method No. Calif. 312, to more accurately reflect the true maximum density that can be achieved in the field for sensitive aggregates. The second was the adaptation of the impact compaction procedure currently used for untreated soils and aggregates, and the third was a field test involving a control strip technique whereby a representative area of the material being placed was compacted until no additional densification of the material could be accomplished. An evaluation of the use of nuclear gages for determining the in-place moisture and density of CTB was also made in connection with the control strip.

These objectives were accomplished through a combination of laboratory and field investigations. This report contains the results of these investigations.

CONCLUSIONS

It was concluded from observations and data collected during this study that existing laboratory procedure for determining maximum density of CTB was a major factor contributing to the difficulties in achieving specified relative compaction for certain aggregate sources. It was found that softer, more angular aggregates were being broken and squeezed together in the laboratory in a way that could not be duplicated under normal field conditions.

The test results also showed that a more realistic maximum density could be established for these problem materials by modifying existing laboratory compaction procedure. These same modifications had very little, if any, effect on the maximum densities of aggregates which were easily compacted in the field.

The modifications of existing laboratory test method developed during this study for determination of maximum density were incorporated in revised Test Method No. Calif. 312-E and the incidence of field compaction problems on cement treated bases has been effectively reduced.

The maximum density results determined by the impact compaction procedure, Test Method No. Calif. 216-F, were very similar to the results determined by Test Method No. Calif. 312-C. The maximum densities determined by the impact procedure would still be unrealistically high for some materials.

Field studies indicated that moisture and density determinations on compacted CTB materials could be made with a reasonable degree of accuracy using nuclear gages. Subsequent to completion of

these field studies, modifications have been made to the nuclear gages and the procedures for their use which should greatly improve the reliability of the test results.

Evaluation of the control strip technique indicates a potential as a field method for determining the maximum density of CTB materials. It would be necessary, however, to place some control on the control strip, either by specifying an equipment and rolling pattern to be used or by relating the control strip densities to a laboratory result. Neither of these methods are considered to be practical at the present time.

IMPLEMENTATION

The laboratory compaction procedures for fabricating CTB test specimens were modified in revised Test Method No. Calif. 312-E dated April 7, 1969 (see Appendix A). The CTB included in contracts awarded subsequent to that date has been tested in accordance with this revised procedure. Because of the reduced compactive effort applied to the control specimens, the incidence of compaction problems on CTB has been effectively reduced.

It is not anticipated that the control strip technique will be pursued further in the near future as long as the laboratory method continues to provide realistic maximum density data for the control of field compaction.

Although not entirely the result of this study, nuclear gages have become the primary means of determining in-place moisture and density of CTB. This technique has greatly reduced the time required for testing.

DISCUSSION AND DATA PRESENTATION

Background

The California Standard Specifications require that CTB materials be compacted to a density which is equal to at least 95 percent of the maximum density that can be achieved with the same material under specified laboratory procedures. The laboratory procedures currently in use can be traced back to a method developed in 1940. Under the original procedure, a test specimen was hand tamped into a 4 inch diameter compaction mold and then further consolidated by applying a 25,000 pound (2000 psi) static load to the confined material. Hand tamping, which was intended to simulate the type of compactive effort applied by a sheepsfoot roller, was done with a 3/4 inch diameter rod until an estimated degree of compaction was achieved. The 25,000 pound static load was then applied to provide the same load per square inch as was being used at that time for static load compaction and bearing ratio tests on untreated roadway materials.

Over the years many refinements had been made in the test method, but Test Method No. Calif. 312-C, which was in effect when this study was started, still incorporated essentially the same compaction procedures. Initial compaction was still done with a 3/4 inch rod and the static load of 25,000 pounds was still being applied. Procedural improvements included rodding the material with a 3/8 inch diameter rod prior to compaction and prescribing the number of blows with the 3/4 inch tamper. Both of these changes contributed to improving the repeatability of the test. Rodding the material before compaction prevented the formation of rock pockets and specifying the number of blows with the tamper decreased the degree to which this phase of the test was dependent upon operator judgement.

The sand volume test, which was adopted in the late 1930's or early 1940's, has been used regularly through the years for determining in-place densities of the compacted materials. This test has also remained essentially unchanged except for improvements in the instructions.

For many years, the prescribed test procedures were used satisfactorily for the design and control of CTB. In more recent years, however, there has been an increasing number of projects where it has been extremely difficult for the contractor to accomplish the required degree of compaction. The effects of these difficulties were further compounded by the fact that completion of the in-place density test is quite time-consuming so that by the time areas of inadequate compaction were identified, the maximum allowable time for applying additional compactive effort had already elapsed.

Evaluation of Laboratory Procedure for Determining Test Maximum Density

To observe and evaluate the differences in compactability being encountered by contractors, four aggregates were selected for comprehensive laboratory studies. Two of the aggregates were selected because of the relative ease with which field compaction could be accomplished. Both of these aggregates turned out to be hard stream gravels. One consisted of almost entirely rounded particles while the other contained some crushed particles.

The other two aggregates were selected because of their past record of being difficult to compact. Both of these aggregates were relatively soft quarry materials.

Cement and water were added to each of these aggregates, and CTB test specimens were fabricated to establish maximum densities and optimum moisture contents in accordance with Test Method No. Calif. 312-C.

The heights of the test specimens were measured as the 25,000 pound static load was applied to determine the amount of consolidation that occurred. The two stream gravels compressed 0.17 and 0.21 inches, respectively, while the quarry aggregate compressed 0.43 and 0.41 inches under the same 25,000 pound load.

The amount of compactive effort required to achieve 95 percent of this test maximum density was then determined for each of the materials. It was found that 95.5 and 95.1 percent relative compaction could be achieved on the two stream gravels by applying only the hand tamping phase of the specified compaction procedure. To achieve a 95 percent relative compaction with the two quarry aggregates, it was necessary to apply static loads of 6000 and 8000 pounds in addition to the hand tamping.

These data supported the hypothesis that the compaction procedures used when determining maximum densities may have been too severe for certain aggregates being used in CTB. At least a portion of the consolidation of these materials was believed to be due to crushing of the particles under the static loading. This type of loading cannot be duplicated in the field and, as a result, contractors were experiencing difficulties in achieving required relative densities even though their methods of operation appeared adequate.

It was concluded that the laboratory compaction procedures should be revised to provide a test maximum density which would more accurately reflect the densities that could be attained with a reasonable compactive effort in the field.

Revised Laboratory Procedure

The preceding data indicated that the laboratory compaction procedure for determining test maximum density was too severe for some materials and was resulting in unrealistically high densities. It was also obvious, however, that any modification should be designed to affect only those materials which were being over-consolidated by the existing laboratory method.

A total of twenty-five procedural variations were tried in an attempt to develop a procedure that would effectively reduce the test maximum density of the softer, more angular, easily crushed materials without appreciably affecting the test maximum densities of the more easily compacted, hard, rounded aggregates. Modifications to the procedure included variations in: number of layers in the test specimen, number of blows with the tamper, diameter of the tamper, total static load, and rate of loading. Two aggregates were tested in this series. One was a blend of river sand and partially crushed river gravel that was easily compacted on the roadway. The other was a crushed product, containing some plastic fines, which had proven to be difficult to compact on the roadway. The results of these tests are presented in Table I.

These data show that for each decrease in compactive effort there was a corresponding decrease in density. None of these modifications, however, were effective in reducing the test maximum density of the crushed aggregate without also reducing the test maximum density of the more easily compacted river gravel.

It was then theorized that a combination of two or more variations might accomplish the desired results. The following changes were incorporated into a proposed revised test procedure:

1. The hand tamper foot diameter was increased from 3/4 inch to 1 inch to distribute the impact over a larger area and decrease the frequency of particle fracturing during this phase of the procedure.
2. The drop of the tamper was increased from 4 inches to 6 inches to compensate for the decrease in compactive effort caused by the increase in tamper end area.
3. The static load was decreased from 25,000 pounds (2000 psi) to 15,000 pounds (1200 psi) to more closely approximate the compactive effort actually applied during field operations.
4. The loose curing time was increased from 30 minutes to one hour \pm 15 minutes to more closely approximate the actual time lapse occurring between mixing and compacting cement treated bases during construction operations.

This last change was included because of the effect that time has on the compactability of cement treated materials. Previous studies have shown that the compacted densities of cement treated materials decrease as the time between mixing and compaction increases when the compactive effort remains constant. In some instances, the compacted density may decrease by as much as 2-1/2 pcf when the curing time is increased from 30 to 60 minutes[3].

The effects of this combination of variations were then evaluated by performing maximum density and optimum moisture tests by both the existing and the proposed procedures. A total of twenty-three aggregates representing easy, average, and difficult-to-compact materials were included. The results of these tests are presented in Table II.

The proposed test method revisions resulted in a decrease in the test maximum density for nearly all of the 23 aggregates tested. For the eight easily compacted materials, the average maximum density decreased 0.6 percent. One material sustained a slight increase in density and another sustained no change in density.

The average maximum density of the eleven materials which were judged to be of average compactability was decreased by 1.6 percent and the average maximum density of the four difficult to compact materials was decreased by 2.2 percent. The density of one of these difficult-to-compact materials was decreased by 3.5 percent, from 138.4 to 133.6 pcf.

It was concluded from this series of tests that the proposed revisions would result in a significant reduction in the test maximum densities of difficult-to-compact CTB materials without appreciably affecting the easily compacted materials. These changes also resulted in some change in the optimum moisture content of the CTB mix. This change was an increase in every case and varied from 0.2 to 1.0 percent moisture.

It was also found that the design cement content, when determined by the proposed procedure, differed from the design cement content determined by the current procedure. The difference varied from 0.5 percent less to 2.0 percent more cement. The average, which was an increase of 0.4 percent cement, has been attributed to the lower densities and increased water content.

Impact Compaction Test

An impact compaction procedure has been used in California since 1928 for determining maximum density of untreated soils and aggregates. This method, which requires compacting the material

into a 2.86 inch diameter mold, was designated as Test Method No. Calif. 216 when the California Division of Highways' Materials Manual was published in 1954. Compaction by this method is accomplished by applying 20 blows with a ten pound tamper to each of five equal layers.

It had been suggested that the overall testing program would be simplified if one compaction procedure could be used for determining the maximum densities of both treated and untreated materials.

To check the feasibility of using Test Method 216 for determining the maximum density of CTB, aggregates from several sources were tested by this procedure and the results compared with results from Test Method 312. Both the then-current method and the proposed revised method for Test Method 312 were compared with Test Method 216. The aggregates tested represented a wide range in characteristics, from rounded river gravel to crushed aggregate, both hard and soft. For these tests the optimum moisture was considered to be the maximum amount that the test specimen could retain when the compactive effort was applied. The maximum densities and optimum moistures tabulated in Table III were determined from test specimens which showed a slight amount (2 to 5 grams) of water being squeezed out during compaction.

The average maximum densities and optimum moisture contents determined by Test Method 216-F were very similar to the results determined by Test Method 312-C. Since the primary difficulty in using Test Method 312 had been the unrealistically high maximum densities for certain aggregate sources, it was obvious that little improvement in the situation could be accomplished by adopting Test Method 216 as the standard.

It was also reasoned that adoption of Test Method 216 for use with CTB materials would probably add confusion to the testing of these materials since it would still be necessary to retain Test Method 312 for use in fabricating specimens for compressive strength tests.

Control Strip Technique

Another possible method of evaluating the compaction of CTB materials is the use of control strips and nuclear moisture-density gages. The Virginia Highway Research Council reported in 1967[4] that they had used control strips successfully for compaction control of granular base course materials on three projects and that they intended to apply this technique on more projects in the future.

The basic concept of the control strip is that a small representative area of the material being placed is compacted on the job site until no additional densification can be achieved. The density of this control strip then becomes the standard, or maximum, density with which the field control test results are compared. To assure proper compaction of the control strip, it is necessary to restrict the use of equipment to that which is known to be adequate. Compaction of the remainder of the roadway can be done by any means which will provide the minimum relative density. Optimum moisture of the mix is determined by laboratory tests.

To assure that the maximum density of the control strip is reasonably correct, it is advisable to average the densities determined at several locations. The Virginia Highway Department reported using an average of ten tests from a control strip having a minimum area of 400 square yards.

The density of the area being tested was then based on the average of five randomly selected sites. The required mean density for these 5 sites was set at 98 percent of the mean density of the control strip. None of the individual test values could be less than 95 percent of the mean density of the control strip.

A field study was initiated to investigate the possibility of applying this control strip technique to the placement of CTB in California. Several construction projects in various areas of California were selected for experimentation. The geographical location of the projects ranged from the southern coastal section of the state to the central interior valley, and the aggregates varied from smooth streambed gravels to crushed quarry rock.

On each of these projects, the placement of CTB was controlled by the standard procedures in use at that time. Nuclear gages were being used for in-place density determinations on some projects while the sand volume test was being used on other projects. The maximum density for control of compaction on each project was determined by laboratory procedures according to Test Method No. Calif. 312-C.

Test Method No. Calif. 312-C did not spell out how the maximum density results were to be applied to the compaction control of materials being placed in the field. A supplemental section was subsequently added to the method explaining the procedure for determining relative compaction. This supplement, which was designated as Test Method No. Calif. 312-D and dated October 2, 1967, also authorized the use of nuclear gages for determining in-place densities of CTB. Although the nuclear gage method was authorized for use it had not previously been statistically evaluated when used to test cement treated materials. Such an evaluation was considered to be a very important prerequisite to the use of the nuclear gage with the control strip technique.

The testing program was therefore designed so that the data obtained would provide a statistical evaluation of the nuclear gages while at the same time providing a basis for evaluation of the control strip technique.

To evaluate the reliability of the nuclear gage for determining in-place density of compacted CTB, an analysis of variance was performed on test data from several of the projects. These analyses were based on data from twenty-five randomly selected locations from each of the projects. Side-by-side moisture and density determinations were made at each location following the general procedure established in Test Method No. Calif, 231. Backscatter and transmission type nuclear gages were used on different projects. Both methods were used on two of the projects.

The results of these analyses of variance are summarized in Table IV.

Most of these data indicate that the overall variance in density test results is about the same when testing cement treated aggregates as has been observed in previous studies on untreated soils [5].

When the overall variance was broken down into sources, it was found that variation in the material itself was a major contributing factor. The relatively small testing variances observed on most of the projects indicate that the nuclear method of determining densities of cement treated aggregates is reasonably accurate.

There were, however, identifiable causes for some of the testing variance. One factor that seriously affected the density readings, when using the backscatter gages, was the surface condition of the compacted material. It was mentioned in the field notes on Project 9, for example, that the surface of the CTB was severely disturbed during the final trimming operation and was left in a very rough condition. This rough surface condition made satisfactory seating of the nuclear gage very difficult.

Another probable source of variation contributing to the testing variance was the design of the transmission gages. All of the gages used in this study were constructed with the detector tube in the rod which was inserted into the material. The detector tube was four inches in length and was contained in the rod in such a way that the depth of the nuclear reading was measured to the midpoint of the tube. Thus, when the depth of the gage was set to correspond to the planned thickness of the layer, the lower half of the detector tube was actually inserted into the underlying material. Variations in the actual thickness of the layer being tested could also present problems since the depth of penetration into the underlying material would not be constant. Despite these known weaknesses in the equipment and testing procedures, the small testing variance and the comparable total variance indicated that the test results were sufficiently accurate to provide a means of evaluating the control strip concept using nuclear gages.

Both of these sources of error have been eliminated from nuclear moisture-density testing equipment now in use by the California Department of Transportation. The test method presently in use makes provision for direct transmission gages only, and requires that the nuclear source be contained in the rod when materials less than eight inches thick are tested. The procedure also prohibits inserting the rod to the full depth of the layer being tested.

It was assumed that the compaction equipment being used on each of these projects was adequate and that the test procedures were providing satisfactory control over the material being placed. The control strips were then compared with the results of the control tests actually in use.

A total of twenty-five (25) control strips were compacted on nine different projects. Each control strip, which was approximately 1200 square feet in area, was selected from within the area being placed on the roadway. Compaction of the control strips was continued, using the same equipment being used on the job, until no further increase in density could be accomplished.

Nuclear moisture-density gages of both the backscatter and transmission types were used to determine densities. In the control strips, the density was determined at one location after successive passes of the compactor until the maximum had been reached. When it was determined that additional compactive effort would be of no significant value, densities were determined at 10 locations within the control strip. The locations for the individual test sites were predetermined according to the size of the control strip. In most cases, the control strip included approximately 100 linear feet of a single lane. Test locations were systematically distributed within this area by selecting companion sites, approximately two to three feet from opposite edges of the strip, at intervals of approximately twenty feet. The densities at these locations were then averaged to establish the maximum density of the control strip.

The remainder of the material being placed was compacted at the discretion of the contractor until the density specifications for the project were met. After it had been decided, using routine procedures, that the material had been satisfactorily compacted, random moisture-density tests were made with the nuclear gages.

A summary of the data obtained from the control strip studies is presented in Table V. The data presented includes the test maximum density values for the test area as determined by Test

Method No. Calif. 312 prior to modification and as determined using the control strip method. It also includes average densities for the street samples and the relative densities of the street samples when compared with each of the two maximum densities.

A comparison of the maximum densities determined by the two methods reaffirms the conclusion that the then current laboratory compaction procedure was too severe and resulted in unrealistically high maximum densities for some materials. On projects 6, 8 and 9, the average densities of the control strips did not exceed 95 percent of the densities determined by the laboratory method. On project 6, when the transmission gage was used the average relative density of the control strip was only 92 percent of the laboratory density. This condition occurred despite the fact that the material in the control strip area was repeatedly rolled until no significant additional compaction could be accomplished. The control strips on Projects 1 and 4, however, were easily compacted on the roadway to densities of 100 percent or more of the laboratory maximum density as per Test Method No. Calif. 312-C.

The densities of routinely compacted materials placed on the project are also included in the table. Each reported density is the average of several tests taken in a designated test area. These densities are compared with the maximum densities for each respective test area and the relative densities are listed in the last two columns.

Once again, it can be seen that it was extremely difficult, and in some cases nearly impossible when using sensitive aggregates, to achieve a 95 percent relative compaction when the then existing laboratory procedure was used to establish the maximum.

When the control strip was used to establish the test maximum density, it was not uncommon for the tests on the street to indicate relative densities of 100 percent or more. The average densities of the street samples were 100 percent of the control strip densities on six of the nine projects.

Two of the remaining projects, Nos. 4 and 7, had average street densities of 97.8 and 96.7 percent, respectively, but on each project one of the two sets of tests showed relative densities of approximately 99 percent. This indicates that on each of these projects, all of the areas probably could have been compacted to nearly 100 percent of the control strip density with very little additional effort.

Project 1 had the lowest average relative density for the street samples. In fact, this was the only project where the relative densities determined by the control strip method were consistently lower than the relative densities based on the laboratory procedure. It should be pointed out, however, that because the aggregates used on this project were so easily compacted, very little effort was needed to achieve the 95 percent relative compaction required by the specification. In all probability, the densities on the street could have been increased significantly with very little additional effort.

In their specifications, the Virginia Highway Department[6] requires that the mean density of 5 randomly selected sites from the test area be at least 98 percent of the density determined from the control strip. They also require that each individual site have a relative density of at least 95 percent.

All of the materials reported in this study either met the requirements set forth by the Virginia Highway Department or, in the opinion of the author, could have met the requirements

with very little additional compactive effort. These materials were also accepted by the control procedures then in effect in California.

The major drawback to adopting the control strip technique was the need to control the compaction process of the control strip itself. Virginia controls the compaction of the control strip by requiring that compaction be carried out with conventional rollers approved by the Engineer. This presents somewhat of a problem in that conventional or acceptable rollers must be defined or listed by name, and a rolling pattern must be prescribed. Such a restriction might hinder the development and application of new compaction equipment since it would be necessary to study the effectiveness of a roller on a variety of materials before it could be accepted for general use. This could also create an inconvenience and additional expense for a contractor if he was required to furnish supplemental rollers because the compaction equipment he intended to use had not been previously qualified.

An alternative would be to require that the control strip density equal or exceed some specified minimum density based on laboratory tests. This is probably not a good solution since in reality the material being placed on a project would actually still be compared with a laboratory compacted sample.

Based on the observations and data gathered during this study, it has been concluded that the control strip technique has good potential as a satisfactory control of the compaction of CTB. There are, however, details in its application which would require further study before it could be implemented.

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TABLE I
EFFECTS OF PROCEDURAL VARIATIONS TO
TEST METHOD NO. CALIF. 312 C

No. of tamps with 6 lb. 3/4" diam. tamper (1)			Total load (2) (lbs)	Loading rate (lbs/min)	Easy to Compact River Sand and Gravel		Difficult to Compact Crushed Aggregate	
1st Layer	2nd Layer				Density lbs/cu.ft.	% Rel. Comp.	Density lbs/cu.ft.	% Rel. Comp.
1	50	100	25,000	20,000	135	100	139	100
2	30	30	"	25,000	132	98	-	-
3	100	100	20,000	20,000	-	-	138.5	99
4	50	100	"	10,000	132.5	98	-	-
5	50	50	"	20,000	132.5	98	136.5	98
6	50(3)	50(3)	"	"	132	98	-	-
7	25	50	"	10,000	131.5	97	-	-
8	30	30	"	20,000	132	98	-	-
9	25	25	"	"	131	97	136	98
10	None	None	"	(4)	130	96	-	-
11	None	None	"	10,000	129	96	-	-
12	100	100	15,000	15,000	132	98	135	97
13	(5)	(5)	"	"	132	98	135.5	98
14	50	50	"	"	131	97	135.5	98
15	50(3)	50(3)	"	"	131	97	-	-
16	25	25	"	"	130	96	135	97
17	None	None	"	(4)	127.5	94	-	-
18	25	25	10,000	10,000	-	-	130.7	94
19	None	None	"	(4)	126.4	94	-	-
20	None	None	"	10,000	125	93	-	-
21	25	25	5,000	5,000	-	-	126.7	90
22	None	None	"	"	120.5	89	-	-
23	None	None	2,000	2,000	118	87	-	-
24	25	25	1,000	1,000	-	-	121.5	87
25	None	None	750	750	113.5	84	-	87

- (1) Each layer rodded 30 times with 3/8" diameter bullet nosed rod.
(2) Total load held for one minute.
(3) A 6 pound, 2" diameter hand tamper was used.
(4) Total load applied three times with a loading rate of one minute for each cycle.
(5) Compacted in three layers with 50 tamps per layer.

TABLE II

COMPARISON OF TEST RESULTS
PROPOSED REVISED METHOD VS. TEST METHOD 312 C

Sample No.	Assessed Field Compactibility	Test Method No. Calif. 312 C Density	% Moist.	Revised Test Method 312 Density	% Moist.	Relative Density Revised Method Vs. TM 312 C
1	EASY	142.2	6.5	140.0	7.3	98.5
2		140.2	6.4	140.1	7.1	99.9
3		137.1	7.0	137.6	7.4	100.4
4		138.5	6.7	136.3	7.6	98.4
5		136.8	7.0	136.7	7.2	99.9
6		134.0	7.5	133.4	7.9	99.6
7		133.9	7.6	133.9	8.1	100.0
8		136.7	7.9	135.1	8.1	98.7
9	AVERAGE	133.9	9.2	131.6	9.9	98.3
10		141.8	8.6	137.7	9.6	97.1
11		135.0	8.6	132.3	9.2	98.0
12		133.8	8.5	131.8	9.4	98.5
13		144.2	7.7	141.1	8.7	97.9
14		139.0	8.0	137.9	8.3	99.2
15		136.0	7.7	133.9	8.0	98.5
16		134.7	7.4	133.5	7.8	99.1
17		134.2	7.9	132.5	8.1	98.7
18		136.4	7.5	135.6	7.7	99.4
19		132.4	9.2	128.6	9.9	97.1
20	DIFFICULT	138.4	8.2	133.6	9.1	96.5
21		122.6	11.9	120.8	12.6	98.6
22		134.0	8.8	131.3	9.4	98.0
23		135.3	8.4	133.0	8.7	98.3

TABLE III

COMPARISON OF MOISTURE/DENSITY DETERMINATIONS
BY IMPACT COMPACTION AND STATIC LOADING PROCEDURES

Sample No.	Test Method Number					
	Calif. 216-F Density (pcf)	Moisture (%)	Calif. 312 C Density (pcf)	Moisture (%)	Calif. 312 Revised Density (pcf)	Moisture (%)
1	140.7	6.6	142.2	6.5	140.0	7.3
2	139.4	7.2	138.5	6.7	136.3	7.6
3	141.9	6.5	140.2	6.4	140.1	7.1
4	132.4	9.2	133.9	9.2	131.6	9.9
5	135.4	9.7	133.8	8.5	131.8	9.4
6	143.4	7.3	144.2	7.7	141.1	8.7
7	138.9	8.0	138.4	8.2	133.6	9.1
Avg.	138.9	7.8	138.7	7.6	136.3	8.4

TABLE IV
ANALYSES OF VARIANCE OF DENSITIES
DETERMINED BY NUCLEAR GAGES

Job I. D.	1	2	3	4	8	8a	9	9a
Type of Gage*	BS	Tran	BS	Tran	BS	Tran	BS	Tran
CTB Thickness	6"	4"	4"	6"	4"	4"	4"	4"
Materials Variance	10.78	2.72	9.65	4.60	10.07	18.72	20.45	31.64
Sampling Variance	4.59	0.06	5.15	--NOT ISOLATED--			-	-
Testing Variance	5.40	3.32	6.53	1.44	6.69	2.62	16.85	3.59
Overall Variance	20.77	6.10	21.33	6.53	16.76	21.34	37.30	35.23
Estimated Sigma	4.56	2.47	4.62	2.56	4.09	4.62	6.11	5.94

*BS -- backscatter gage

Tran -- direct transmission gage

TABLE V
COMPARISON OF RESULTS DETERMINED BY CONTROL STRIP
AND TEST METHOD 312 C

Proj.	Test No.	Assessed Compact-ability & Thickness	Type of Nuclear Gage	Dry Max. Density by Lab. Proc.	Cont. Strip	Dry Density of Street Samples	Relative Density of Street Samples to TM312C Cont. Strip	
1	1	easy 6"	BS	134.2	137.3	131.6	98.1	95.8
	2		"	135.5	*	133.0	98.2	96.9
	3		"	137.2	137.9	135.0	98.4	97.9
	4		"	137.4	139.0	131.5	95.7	94.6
2	1	avg. 4"	Tran	133.3	128.5	130.7	98.0	101.7
	2		"	135.2	*	128.6	95.1	100.0
	3		"	134.0	129.5	128.7	96.0	99.4
3	1	avg. 4"	BS	139.0	138.2	139.2	100.1	100.7
	2		"	136.5	138.2	137.3	100.6	99.3
	3		"	140.1	135.3	137.5	98.1	101.6
	4		"	142.8	137.2	140.7	98.5	102.6
4	1	easy 6"	BS	132.8	131.8	127.2	95.8	96.5
	2		"	*	133.7	132.5	99.8	99.1
5	1	avg. 4"	Tran	138.8	133.0	133.7	96.3	100.5
	2		"	145.2	136.6	135.9	93.6	99.5
	3		"	139.7	137.1	137.1	98.1	100.0
6	1	very difficult 4"	BS	121.9	111.8	115.1	94.4	103.0
	2		"	124.2	119.9	120.2	96.8	100.3
	3		"	129.2	122.7	117.3	90.8	95.6
	4		"	126.1	116.8	120.6	95.6	103.3
	1a		Tran	121.9	114.4	112.0	91.9	97.9
	2a		"	124.2	114.8	118.8	95.7	103.5
	3a		"	129.2	119.8	114.3	88.5	95.4
	4a		"	126.1	114.2	115.7	91.8	101.3
7	1	avg.	BS	138.5	135.2	127.9	92.3	94.6
	2		"	138.1	134.1	132.5	95.9	98.8
8	1	difficult 8" (two layers)	Tran	137.9	129.7	131.0	95.0	101.0
9	1	4"	BS	141.4	137.6	138.5	97.9	100.7
	2			145.1	133.2	134.4	92.6	100.9
	3			142.8	136.6	134.8	94.4	98.7
	4			144.0	137.4	136.8	95.0	99.6
	1a		Tran	141.4	140.6	137.8	97.5	98.0
	2a			145.1	131.2	134.6	92.8	102.6
	3a			142.8	133.8	137.3	96.1	102.6
	4a			144.0	133.1	135.6	94.2	101.9

* No Data
BS -- backscatter gage
Tran -- direct transmission gage

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DESIGN AND TESTING OF CLASSES "A" AND "B" CEMENT TREATED BASES**Scope**

The procedure for determining the proper cement and moisture contents to be combined with available aggregates in the preparation of cement treated bases is described in this test method. Procedures for determining compressive strengths of test specimens and for determining relative compaction of cement treated bases are also described.

This test method is divided into the following parts:

- I. Preparing Laboratory Processed Materials.
- II. Field Sampling and Preparation Procedures.
- III. Fabricating and Curing Test Specimens.
- IV. Determining Optimum Moisture, Cement Content and Test Maximum Density.
- V. Determining Compressive Strength.
- VI. Calculating Percent Relative Compaction.

PART I. PREPARING LABORATORY PROCESSED MATERIALS**Scope**

The preparation of aggregates and the batching and mixing of materials for fabricating compressive strength test specimens is described in this part.

A. Apparatus

1. Scales, 5,000 gram capacity, accurate to 1 gram.
2. Water spray metering device with turntable.
3. Mixing pan and trowel or spoon.

B. Test Record Form

Use Form HMR T-342, "Laboratory Record of Cement Treatment", for recording test data.

C. Preparing Laboratory Processed Materials

1. Aggregate samples submitted for cement treatment tests are divided into three categories:

a. Processed. Materials which will not be subjected to any further processing prior to mixing with cement, such as bin samples, windrow samples and some stockpile samples.

b. Unprocessed. Materials which will require additional processing to attain a satisfactory grading such as pit samples, quarry samples and some stockpile samples which require scalping, crushing, blending, etc.

c. In-place. Materials which are part of an existing road which will be scarified, pulverized and mixed with cement.

2. Initial preparation of all samples is to be done in accordance with Test Method No. Calif. 201, except that in-place materials containing lumps of bituminous mix should have the lumps reduced in size to pass a one-inch sieve and no sieve analysis is required.

3. Determine the moisture content of representative samples of coarse and fine aggregates according to the procedures described in Test Method No. Calif. 226.

4. Determine the desired grading for the sample.

a. The grading as determined on a sample prior to any adjustment such as scalping, wasting or crushing, is known as the "as received" grading. Before a material can be tested, it is often necessary to adjust the grading either to meet specifications or to eliminate material too large to test. This adjusted grading is referred to as the "as used" grading. See Test Method No. Calif. 905 for methods of adjusting grading. In cases where 100 percent of the material as received passes the 1 inch sieve and no adjustments are necessary, the "as received" and the "as used" gradings will be the same.

b. Using the sieve analysis of the sample or samples to be tested, design the mix to conform to the specified grading limits by blending or adjusting as necessary. Designing to a smooth grading curve approximately in the middle of a specified range is desirable but not always essential. General practice is to produce the best possible grading within the specification limits with the material on hand, but any adjustment should be such that it can be duplicated under actual field conditions.

c. In cases where an aggregate size larger than 1 inch maximum is specified, waste (scalp) the aggregate retained on the 1 inch sieve.

5. Estimate the required amount of material necessary to fabricate a 4 inch diameter x 4 inch high test specimen.

a. Most well graded aggregates have dry densities within the range of 130 to 145 pounds per cubic foot. Density of the aggregate can be estimated fairly close with some experience.

b. To convert the estimated density to total weight, in grams, of aggregate and cement required for a 4 inch x 4 inch test specimen, the following formula may be used: $W_g = 13.2 W_f$

W_g = Dry weight in grams of 4 inch x 4 inch compacted test specimen.

W_f = Dry density in pounds per cubic foot of compacted test specimen.

13.2 = Constant used to convert pounds per cubic foot to weight in grams for a 4 inch diameter by 4 inch high specimen.

Example:

Assume a density of 130 pounds per cubic foot for a trial specimen. Substituting in the above formula,

$$W_g = 13.2 \times 130 = 1716 \text{ g.}$$

This weight includes the weight of cement as well as the weight of the aggregate. The following formula is used to calculate the weight of the aggregate only.

Test Method No. Calif. 312-E

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$$W_a = \frac{W_o}{100 + C} \times 100$$

Where:

W_a = Dry weight of aggregate.

W_o = Dry weight of aggregate + cement.

C = Percent of cement in the mix.

Using a total dry weight of 1716 g. and a cement content of 5 percent, substitute in above formula.

$$W_a = \frac{1716}{100 + 5} \times 100$$

$$= 1634 \text{ g. of aggregate.}$$

Subtracting the aggregate weight from the total dry weight gives the weight of cement.

$$1716 - 1634 = 82 \text{ g. of cement.}$$

c. In order to simplify the procedure for calculating the amount of aggregate and cement to be used in fabricating one 4 inch x 4 inch test specimen, Table I is provided. This table gives dry weights of materials in grams required to produce one 4 inch x 4 inch test specimen with cement contents varying from 2 percent to 8 percent by weight, and densities varying from 107 to 150 pounds per cubic foot. If quantities of material are needed to make specimens with a density lower than 107 or higher than 150 pounds per cubic foot the above formula must be used. All the specimens shall have a measured height after compaction of 4.000 ± 0.200 inches.

To obtain weight of aggregate, subtract weight of cement from total weight of cement and aggregate.

Example: Assume a dry density of 130 lb. per cu. ft. and a cement content of 5 percent. From Table I,

Weight per cu. ft.	Grams of cement and aggregate	Grams of Cement
130	1,716	82

$$\text{Weight of aggregate} = 1,716 - 82 = 1,634 \text{ g.}$$

6. Convert the desired grading of the material to percent of the sample in each increment size.

Sieve Size	Percent Passing	Increment Size	Percent of Sample
1"	100	1" x 3/4"	4
3/4"	96	3/4" x 1/2"	6
1/2"	90	1/2" x 3/8"	10
3/8"	80	3/8" x No. 4	20
No. 4	60	Pass No. 4	60

7. Calculate the required dry weights of each increment size on the basis of the total weight estimated in Section C-5.

Increment Size	Percent of Sample	Total Dry Wt. in Grams	Wt. of each Increment Size in Grams
1" x 3/4"	4 x .01	1634	65
3/4" x 1/2"	6 x .01	1634	98
1/2" x 3/8"	10 x .01	1634	163
3/8" x No. 4	20 x .01	1634	327
Pass No. 4	60 x .01	1634	981
Total	100		1634

8. Adjust the batch weights to compensate for the moisture in the material and record the cumulative weights.

Increment Size	Wt. of Each Increment Size in Grams	% Moisture	Adjusted Wt. in Grams	Cumulative Batch Wt. in Grams
1" x 3/4"	65	.8	66	66
3/4" x 1/2"	98	.8	99	165
1/2" x 3/8"	163	.8	164	329
3/8" x No. 4	327	.8	330	659
Pass No. 4	981	1.2	993	1652

9. Separate the passing No. 4 material into representative portions of the approximate quantity needed for each specimen. Weigh out the exact amount of passing No. 4 material according to the batch weights calculated in Section C-8.

10. Recombine the coarse and fine aggregates according to the batch weights calculated in Section C-8.

TABLE I
TABLE OF WEIGHTS FOR USE IN FABRICATING
4-IN. DIAM. x 4-IN. HIGH TEST SPECIMENS
OF VARIOUS WEIGHTS PER CU. FT.

Pounds per cubic foot	Total grams cement + agg.	Grams cement						
		2 percent	3 percent	4 percent	5 percent	6 percent	7 percent	8 percent
107	1,412	28	41	54	67	80	92	105
108	1,426	28	42	55	68	81	93	106
109	1,439	28	42	55	69	82	94	107
110	1,452	29	42	56	69	82	95	108
111	1,465	29	43	56	70	83	96	109
112	1,478	29	43	57	70	84	97	109
113	1,492	29	44	57	71	85	98	110
114	1,505	30	44	58	72	85	99	111
115	1,518	30	44	58	72	86	99	112
116	1,531	30	45	59	73	87	100	113
117	1,544	30	45	59	74	87	101	114
118	1,558	31	45	60	74	88	102	115
119	1,571	31	46	60	75	89	103	116
120	1,584	31	46	61	75	90	104	117
121	1,597	31	47	61	76	90	105	118
122	1,610	32	47	62	77	91	105	119
123	1,623	32	47	62	77	92	106	120
124	1,637	32	48	63	78	93	107	121
125	1,650	32	48	64	79	93	108	122
126	1,663	33	49	64	79	94	109	123
127	1,676	33	49	65	80	95	110	124
128	1,690	33	49	65	81	96	111	125
129	1,703	33	50	66	81	96	111	126
130	1,716	34	50	66	82	97	112	127
131	1,729	34	50	67	82	98	113	128
132	1,742	34	51	67	83	99	114	129
133	1,756	35	51	68	84	99	115	130
134	1,769	35	52	68	84	100	116	131
135	1,782	35	52	69	85	101	117	132
136	1,795	35	52	69	86	102	118	133
137	1,808	36	53	70	86	102	118	134
138	1,822	36	53	70	87	103	119	135
139	1,835	36	53	71	87	104	120	136
140	1,848	36	54	71	88	105	121	137
141	1,861	37	54	72	89	105	122	138
142	1,874	37	55	72	89	106	123	139
143	1,888	37	55	73	90	107	124	140
144	1,901	37	55	73	91	108	124	141
145	1,914	38	56	74	91	108	125	142
146	1,927	38	56	74	92	109	126	143
147	1,940	38	57	75	92	110	127	144
148	1,954	38	57	75	93	111	128	145
149	1,967	39	57	76	94	111	129	146
150	1,980	39	58	76	94	112	130	147

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11. Mix the individual test specimens in the following manner:

a. Mix together the proper proportion of aggregates and cement prior to adding water. After the dry ingredients are thoroughly mixed, add the required amount of water and continue mixing until all of the aggregates are coated. The required amount of water to be added to the aggregates and cement is determined by the procedures outlined in Part IV.

b. Any mechanical mixer which will produce a homogeneous mix may be used, or the materials may be mixed with a trowel or spoon in a mixing pan.

c. After mixing, place the aggregate-cement-water mixture in a can and cover with a tight fitting lid for a period of one hour \pm 15 minutes before compacting the individual test specimens.

12. Figure I shows a sample form for calculating batch weights and for recording fabrication data.

Increment Size	Percent of Sample	Total Dry Wt. gms.	Weight of Increment Size in gms.	Percent Moisture	Adjusted Weight gms.	Cumulative Batch Wt. gms.
1" x 3/4"	4 x .01	x 1634 =	65	0.8	66	66
3/4" x 1/2"	6 x .01	x 1634 =	98	0.8	99	165
1/2" x 3/8"	10 x .01	x 1634 =	163	0.8	164	329
3/8" x No.4	20 x .01	x 1634 =	327	0.8	330	659
Pass No.4	60 x .01	x 1634 =	981	1.2	993	1652

Test Specimen	1-A				
a. Dry Wt. Agg.	1634				
b. Cement	3 % 49	%	%	%	%
c. Agg. & Cement (a+b)	1683				
d. Initial Moisture	18 XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
e. Added Moisture	133 XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
f. Total Moisture (d+e)	9 % 151	%	%	%	%
g. Batch Wet. Wt. (c+f)	1834				
h. Adjusted Wet Wt.	1831				
i. Liner	81				
j. Gross Wt. Before Comp.(h+i)	1912				
k. Gross Wt. After Comp.	1905				
l. Exuded Water (j-k)	7				
m. Gage Reading	.501				
n. Height (m+3.5)	4.001				
p. Dry Density, pcf	127.2				
q. Days Cured	7				
r. Total Compressive Load	8210				
s. Compressive Strength, psi	655				

$$\text{Dry Density} = \frac{30.3 \times \text{Adjusted Wet Wt.}}{(100 + \% \text{ Moisture}) \text{ Height}}$$

$$\text{Compressive Strength, psi} = \frac{\text{Total Compressive Load}}{12.57}$$

or

$$\text{Total Compressive Load} \times .08$$

FIGURE I

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PART II. FIELD SAMPLING AND PREPARATION PROCEDURES**Scope**

The methods for sampling and preparing cement treated base mixtures for fabrication of test specimens are described in this part.

A. Apparatus

1. Shovel.
2. Closed container.
3. Sieve, U.S. Standard 1 inch size.
4. Scales, 5000 gram capacity, accurate to 1 gram.

**State of California
Division of Highways**

MATERIALS & RESEARCH DEPARTMENT

**REPORT OF TESTS ON
CEMENT TREATED BASE
CONTROL SAMPLES**

District 05 County Mon Route 101 P.M. 38.8/43.5
 Contract Number 025234 Date 10-7-68
 Material Type C. B. CTB Sampled By D.L. Durr

Sampling Data	Test Specimen	1-A			
	Time Mixed	0830			
	Station	19+50			
	Location	35' L. &			
	Specified % Cement	3			
Moisture	a. Wet Weight	1375			
	b. Dry Weight	1290			
	c. Tare	350			
	d. Net Dry Wt. (b-c)	940			
	e. Water (a-b)	85			
	f. % Moisture	9.0			
Specimen Data	g. Wet Weight	1834			
	h. Adjusted Wet Wt.	1831			
	i. Liner	81			
	j. Gross Wt. before Comp. (h+i)	1912			
	k. Gross Wt. after Comp.	1905			
	l. Exuded Water (j-k)	7			
	m. Gage Reading	.501			
	n. Height (m+3.5)	4.001			
	p. Density, PCF, dry <input checked="" type="checkbox"/> wet <input type="checkbox"/>	127.2			

$$\text{Density (dry)} = \frac{30.3 \times \text{Adjusted Wet Wt.}}{(100 + \% \text{ Moisture}) \text{ Height}}$$

$$\text{Density (wet)} = \frac{0.303 \times \text{Adjusted Wet Wt.}}{\text{Height}}$$

$$\% \text{ Moisture} = \frac{\text{Wet Wt.} - \text{Dry Wt.}}{\text{Net Dry Wt.}} \times 100$$

FIGURE II

B. Test Record Form

A sample form is shown in Figure II, but any suitable form can be used.

C. Sampling and Preparation of Cement Treated Base Mixture

1. Obtain a representative sample of the cement treated base mixture from the street immediately before the first pass of the roller. Obtain at least enough material to fabricate two compressive strength specimens and a moisture sample. Record the location of the sample site and the time the water, cement and aggregate were mixed.

2. Place the material in a closed container for transportation to the point of fabrication. The test specimens must be fabricated one hour \pm 15 minutes after water is mixed with the cement and aggregate. When initial rolling is started more than one hour after mixing, sample the cement treated base mixture immediately before the first pass of the roller and fabricate the test specimens as soon as possible.

3. When the aggregate contains particles larger than one inch, screen the sample through a one inch sieve and discard all aggregate retained on the one inch sieve. Only the minus one inch material is used for making test specimens.

4. Obtain representative portions of material needed for a moisture determination and for fabricating two test specimens. See Part I for a description of how to estimate the weight of material needed for test specimens.

5. Carefully adjust the amount of material to obtain the weight required for each test specimen.

6. Determine the moisture content of the material according to the procedures described in Test Method No. Calif. 226.

7. If the moisture content of the sample is not within the proper range, it should be adjusted according to the procedures described in Part IV.

8. Fabricate two test specimens according to the procedures described in Part III.

PART III. FABRICATING AND CURING TEST SPECIMENS**Scope**

The procedures for fabricating and curing test specimens are described in this part. The procedures and equipment for use in a field construction laboratory and in a central laboratory are included.

A. Apparatus

1. Compaction mold.

a. Split compaction mold and accessories shown in Figure III.

or

b. Solid wall compaction mold and accessories shown in Figure IV.

2. Compression testing machine.

a. Frame and hydraulic jack shown in Figure V for field testing.

or

b. Any suitable testing machine for laboratory use.

3. Sample extractor shown in Figure VI for use with solid wall mold.

4. Measuring gage and accessories shown in Figure VII.

5. Bullet nosed rod, $\frac{3}{8}$ inch diameter.

6. Hand tamper, one inch diameter weighing 6 ± 0.05 pounds.

7. Scales, 5000 gram capacity, accurate to 1 gram.

8. Four inch x four inch tin liners and caps.

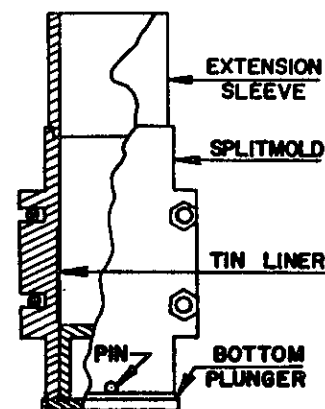
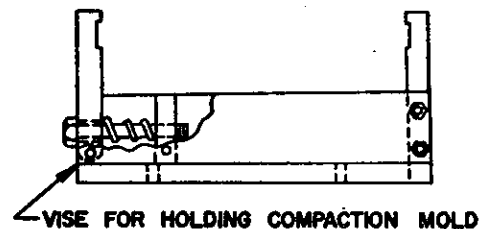
9. Masking or adhesive tape.

10. Shipping cartons.

B. Assembly of the Compaction Mold

1. Split Compaction Mold.

a. Position a tin liner inside the split compaction mold as shown in Figure III and firmly tighten the lock bolts.

**SPLIT COMPACTION MOLD****FIGURE III**

b. Insert the bottom plunger and fasten in place with the pin. The bottom plunger must be positioned so that the rim of the mold does not come in contact with the plunger before compaction is completed. Several holes are provided in the bottom plunger so that its position can be adjusted according to the type of material being tested. Use the lowest hole when testing granular material which does not compress appreciably. Use one of the upper holes when testing fine grained materials which will compress.

c. Place the extension sleeve on top of the assembled mold. The split mold is now ready for fabricating the testing specimen.

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2. Solid Wall Compaction Mold.

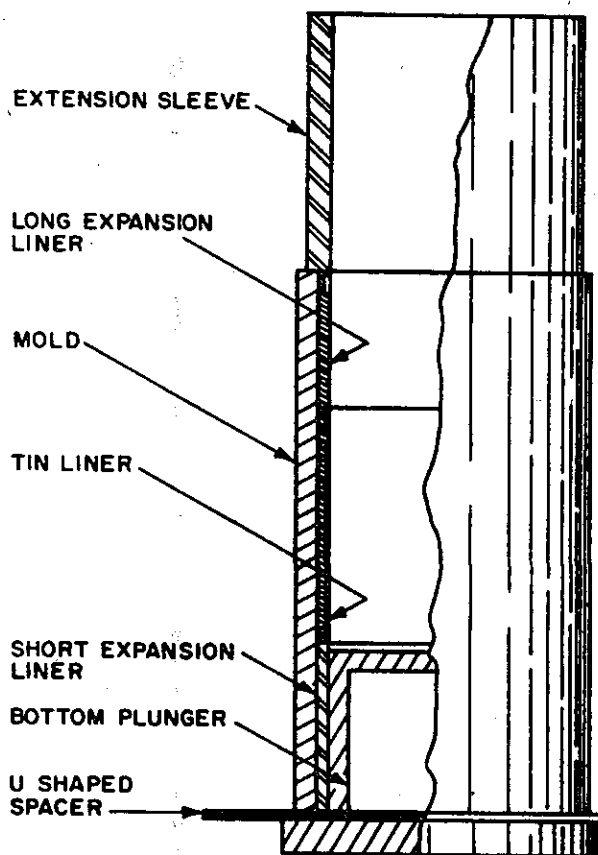
a. Position a tin liner inside, and at the lower end, of the long expansion liner as shown in Figure IV.

b. Insert the long expansion liner into the top of the compaction mold so that the ends of the expansion liner and mold are flush and the tin liner is positioned toward the center of the mold.

c. Insert the short expansion liner from the opposite end of the mold until butted against the tin liner and long expansion liner.

d. Insert the bottom plunger into the short expansion liner.

e. Insert a U-shaped spacer between the bottom of the mold and the bottom plunger. A set of these spacers should be available with thicknesses of $\frac{1}{16}$ inch, $\frac{1}{8}$ inch and $\frac{3}{16}$ inch, so that the proper spacing can be used to prevent the rim of the mold from coming in contact with the bottom plunger before compaction is completed. Use the thin spacer when compacting granular materials which do not compress appreciably and the thicker spacers when compacting fine grained materials which will compress.



SOLID WALL COMPACTION MOLD

FIGURE IV

f. Place the extension sleeve on top of the assembled mold. The solid wall mold is now ready for fabricating the test specimen.

C. Fabricating Test Specimens

1. Prepare the material for fabricating test specimens according to the instructions in Part I for laboratory prepared samples and according to the instructions in Part II for construction control samples.

2. At the end of the one hour \pm 15 minute loose curing period, place the prepared samples in the compaction mold in accordance with the following instructions. Care must be taken to avoid losing material during fabrication of the test specimen.

a. Pour approximately one-half of the material into the mold.

b. Rod the material 30 times with the $\frac{3}{8}$ inch bullet nosed rod to prevent the formation of rock pockets at the bottom or sides of the specimen.

c. Tamp the first layer of material with 50 blows of the six pound tamper. Tamping is accomplished by allowing the tamper to drop free from a height of six inches above the surface of the material being tamped. Guide the tamper over the entire surface of the specimen to obtain uniform density.

d. Pour the remaining portion of the sample into the mold.

e. Rod the material 30 times with the $\frac{3}{8}$ inch bullet nosed rod. When rodding the second layer, the rod should penetrate slightly into the underlying layer with each stroke. This will prevent the formation of a compaction plane between the two layers.

f. Tamp the second layer with 100 blows of the tamper falling free from a height of six inches.

g. Smooth off and level the top of specimen by additional light tamping with the hand tamper. The intent is to make a smooth surface on an even plane at right angles to the axis of the mold.

3. Remove the extension sleeve from the mold.

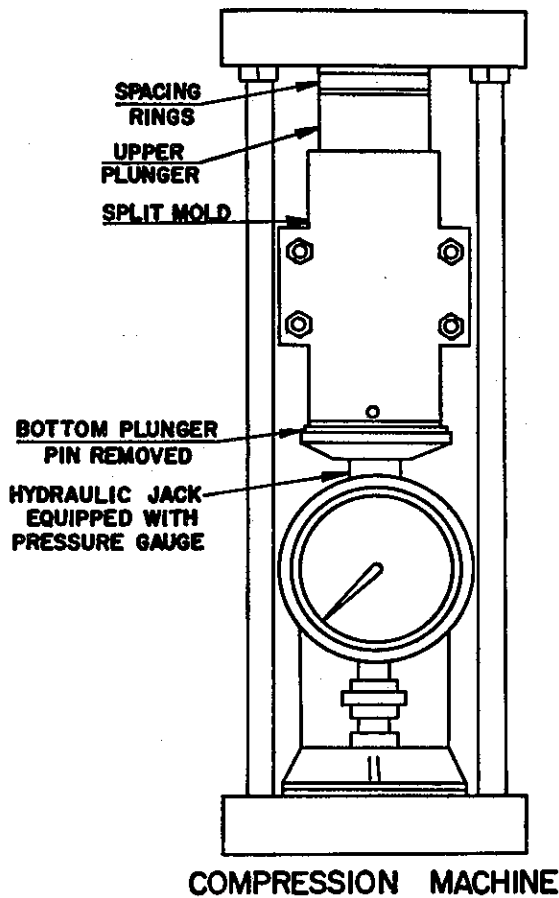
4. Calculate the adjusted wet weight of the specimen which is used for calculating the density of the specimen. Even under laboratory conditions there is some unavoidable loss of material during fabrication.

a. When using the solid wall mold, weigh the mold, liner and specimen after tamping, then subtract the weight of the mold and liner. This is the adjusted wet weight of the specimen.

b. When using the split mold, estimate the adjusted weight. The split mold is usually too heavy to weigh on available scales. The weight loss is considered to be a constant value for an experienced operator and should not exceed two or three grams. Subtract the estimated weight loss from the batch wet weight to obtain the adjusted wet weight.

5. Seat the upper plunger on top of the specimen and place the mold assembly in the testing machine.

6. Remove the pin or spacer from the mold so the bottom plunger is free to move. This provides a double plunger action and results in a more uniformly compacted specimen.



COMPRESSION MACHINE

FIGURE V

7. Uniformly apply a 15,000 pound load in one minute. Hold the 15,000 pound load for one minute and gradually release it.

8. Remove the specimen in its tin liner from the mold. When the solid wall mold is used the sample extractor shown in Figure VI can be used.

9. Weigh the specimen and tin liner to the nearest gram.

10. Measure the height of the specimen to the nearest 0.001 inch. The specimen must be 4.000 ± 0.200 inches high. If it is not, discard the specimen and make a new one.

a. Using the gage shown in Figure VII take three or more readings (more than three readings should be taken when the surface of the specimen is rough) between the center and edge of the specimen. The height is reported as the average of these readings.

b. The average height of the specimen may be determined by using the tripedal block. Set the block on top of the specimen and one reading will determine the average height.

c. The accuracy of the measuring gage should be frequently checked with the calibration bar fur-

nished with the gage. Using the calibration bar, set the gage to read 0.500 inches. When measuring a specimen, the gage reading is added to 3.500 inches to determine the actual height of the specimen.

11. Place caps on each end of the specimen and seal with tape.

12. Mark each specimen for identification purposes.

13. Cure the specimens for seven days at room temperature. Perform compressive strength tests on the seventh day according to the procedures described in Part V.

14. Cure specimens fabricated in the field for construction control purposes in the field laboratory for two days before shipping to the District Laboratory for testing. They must arrive in the District Laboratory by the sixth day after fabrication. Cardboard shipping cartons that hold four test specimens are available.

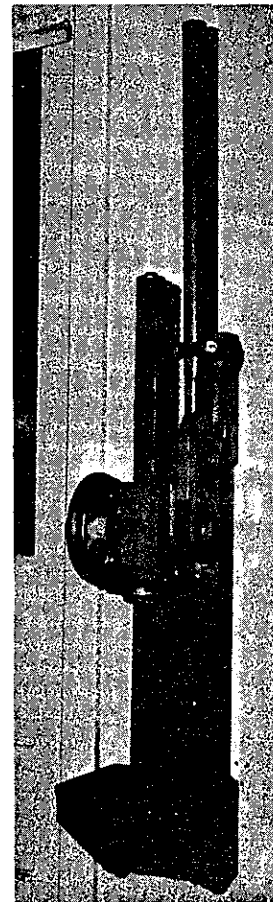


FIGURE VI

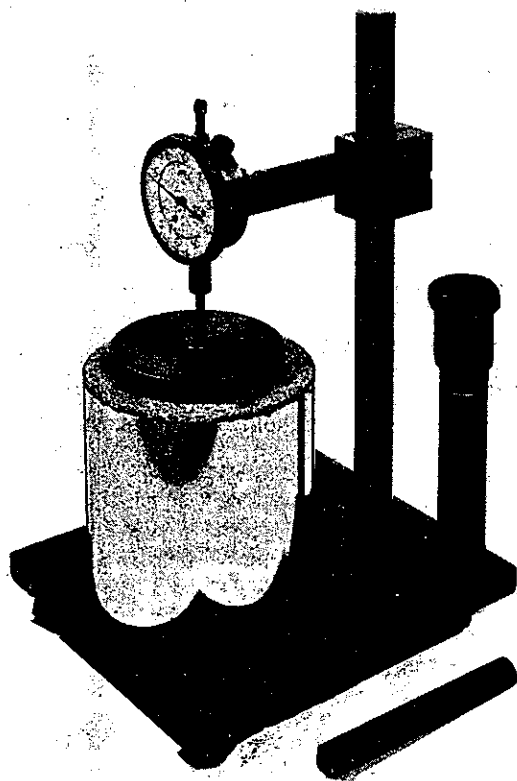


FIGURE VII

PART IV. DETERMINING OPTIMUM MOISTURE, CEMENT CONTENT AND TEST MAXIMUM DENSITY

Scope

The procedures for determining optimum moisture content and recommended cement content for preliminary design samples and for determining optimum moisture content and test maximum density for construction control samples are described in this part.

A. Preliminary Design Samples

1. Optimum moisture content.

a. Optimum moisture is the moisture content required to attain the best compaction results in the field. This moisture content can be estimated in the laboratory by the amount of water exuded from the material during fabrication of the test specimen. A sample from which one to six grams of water are exuded is considered to be at optimum moisture.

b. Prepare material for one or more test specimens in accordance with Part I. Use the same aggregate grading and cement content for each specimen.

c. Add water to the first specimen in small increments until visual inspection and hand squeezing of the mixture indicate sufficient water has been added to provide a cohesive mixture.

d. Compact the specimen in accordance with Part III.

e. Determine the grams of water exuded by subtracting the gross weight of the compacted specimen from the adjusted gross weight before compaction.

f. Determine the height of the specimen as described in Part III.

g. Calculate any adjustments in sample weight and/or moisture content necessary to obtain the required 4.000 ± 0.200 inch high specimen and one to six grams of exuded water.

h. Continue to fabricate new specimens until one is obtained that has both the proper height and moisture content. With experience, no more than two or three trials should be necessary.

i. Cure the final specimen and test for compressive strength. The compressive strength of this specimen can be used in selecting the recommended cement content.

j. The amount of water added to the CTB mixture in the field is sometimes higher than the laboratory determined optimum moisture content. This allows for the evaporation that inevitably takes place during construction operations.

2. Recommended cement content.

a. The recommended cement content is the amount of cement required to insure that field fabricated control specimens will attain desired compressive strengths.

b. Fabricate, at different cement contents, as many test specimens as necessary to span the desired compressive strength. Use the optimum moisture content determined above to prepare the test specimens in accordance with Part I.

c. Cure the specimens and test for compressive strength.

d. From the compressive strengths of the test specimens determine the amount of cement necessary to meet strength requirements. Because of difficulties in uniformly mixing treated aggregates in the field, and because of other variables inherent in the construction process, it is necessary to specify 0.5 to 1.0 percent more cement in the field than is needed to meet the strength requirements under laboratory conditions.

B. Field Control Samples

1. Test Maximum Density.

a. The test maximum density is the average density, in pounds per cubic foot, of two test specimens fabricated from material which has been sampled and tested in accordance with Parts II and III and the instructions below.

b. The material used for test maximum density must have a moisture content which will result in the exudation of between one and 25 grams of water from each specimen during the fabrication process.

1. If no water is exuded from a specimen it must be discarded and sufficient water added to the remainder of the sample so that one to 25 grams of water will be exuded from each of the two specimens. When water is added to the material, a new moisture sample must be taken and this moisture content used in calculating the dry density.

2. If more than 25 grams of water is exuded from a specimen the sample is spread in a thin layer in an open pan and allowed to air dry, with occasional stirring, to the proper moisture content. No artificial heat should be used to dry the sample. The test specimens must still be fabricated within the one hour \pm 15 minute time limit. If it is not possible to adequately air dry the sample, the entire sample must be discarded and a new one obtained from drier material.

c. Determine the grams of water exuded by subtracting the gross weight of the compacted specimen from the adjusted gross weight before compaction.

d. All specimens used for determining test maximum density must be fabricated within one hour \pm 15 minutes after water is mixed with the cement and aggregate as previously specified in this test method. When initial rolling is started more than one hour after mixing, sample the cement treated base mixture before the first pass of the roller (as described in Part II) and fabricate the test specimens as soon as possible.

e. Specimens used for determining test maximum density are cured and tested for compressive strength to meet the frequency of sampling required in the construction manual.

C. Calculating Densities of Test Specimens

1. Dry density is always used for preliminary design samples. Wet density may be used for calculating relative compaction of field control samples only when the moisture content of the in-place density sample does not vary more than one percentage point from the moisture content of the test maximum density sample. Dry density must be used in case of dispute.

2. Use the following formulas to calculate densities:

$$D_d = \frac{30.3 W_w}{(100 + M) H}$$

$$D_w = \frac{0.303 W_w}{H}$$

Where:

D_d = Dry density of the test specimen in pounds per cubic foot.

D_w = Wet density of the test specimen in pounds per cubic foot.

W_w = Adjusted wet weight, in grams, of the test specimen before compaction.

M = Percent moisture in the sample before compaction.

H = Height of the compacted test specimen to the nearest 0.001 inch.

PART V. DETERMINING COMPRESSIVE STRENGTH

Scope

The procedure for capping and breaking test specimens and for determining their compressive strength are described in this part.

A. Apparatus

1. Compression testing machine with spherically seated head.
2. Two 6 inch x 6 inch glass plates for each specimen.
3. Mixing bowl and spoon.
4. Plaster of paris.
5. Water tank for immersing test specimens.

B. Preparation of Specimens

1. On the morning of the seventh day of the curing period, remove the lids and tin liner from each specimen. Transfer the identifying marks to the side of each specimen with a felt tip pen, grease pencil or other suitable marking device.

2. Immerse the specimens in water for six \pm one hours to complete the seven day curing period.

3. Remove the specimens from the water bath and cap both ends of each specimen with plaster of paris as follows:

a. Lay out two glass plates for each specimen. Lubricate one surface of each glass plate with kerosene or lubricating oil to prevent the plaster of paris from sticking to the glass plate.

b. Mix enough plaster of paris with water to form a thick paste for capping both ends of each specimen.

c. Place a spoonful of paste on top of each specimen and immediately force one of the plates down on the paste to form a full cap on top of each specimen.

d. Place a spoonful of paste on each of the other glass plates and force each specimen down on the paste to form a full cap on the bottom of each specimen.

e. Adjust the specimens while the plaster is still soft so that the top and bottom plates are parallel and as nearly as possible at right angles to the vertical axis of the test specimen. A small level may be used to facilitate this operation.

f. Allow the plaster caps to harden for 30 to 40 minutes and then remove the glass plates by tapping the edges lightly with a piece of soft wood. If the glass plates are difficult to remove, apply warm water to the plates and continue tapping lightly.

C. Testing of Specimens

1. The specimen may be tested for compressive strength as soon as the glass plates are removed. Center the specimen directly in line with the spherically seated head of the testing machine. Apply the load at the rate of 12,000 \pm 2,000 pounds per minute. Apply the load continuously and without shock.

2. Increase the load until the specimen fails. Initial fracturing may begin to occur at approximately 90 percent of the maximum load, but loading should continue until the maximum load is attained.

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D. Reporting of Results

1. Report the test results on Form HMR T-342.
2. Report the test results as compressive strength in pounds per square inch, which equals the total compression load divided by the end area of the test specimen.

For the standard four inch diameter test specimen, the end area is 12.57 square inches.

An optional method for calculating compressive strength is to multiply the total compression load by 0.080.

PART VI. CALCULATING PERCENT RELATIVE COMPACTION

Scope

The procedures for calculating percent relative compaction are described in this part.

A. Test Record Form

1. When in-place densities are determined with the sand volume apparatus (Test Method No. Calif. 216), use Form HMR T-297 for recording test data and for reporting percent relative compaction.
2. When in-place densities are determined by the use of nuclear gages (Test Method No. Calif. 231), use Form HMR T-2124 for recording test data and for reporting percent relative compaction.

B. Calculating Percent Relative Compaction

1. Use the following formula for calculating percent relative compaction:

$$\text{Percent relative compaction} = \frac{\text{In-place density}}{\text{Test maximum density}} \times 100$$

2. Percent relative compaction may be calculated using in-place dry density and test maximum dry density or in-place wet density and test maximum wet density. Wet densities may be used only when the moisture content of the in-place density sample does not vary more than one percentage point from the moisture content of the test maximum density sample. In case of dispute, use dry densities for calculating percent relative compaction.

3. Test maximum density is determined by the procedures outlined in Part IV of this test method.

4. In-place density may be determined by the use of nuclear gages as described in Test Method No. Calif. 231 or with the sand volume apparatus described in Test Method No. Calif. 216.

5. When using the sand volume apparatus, perform the in-place density test within 5 feet of the test maximum density sample site. Instructions for taking the test maximum density sample are given in Part II of this test method. When using nuclear gages to determine in-place density the test maximum density sample site should be in the approximate center of the test area.

6. There may be times when it is necessary to perform additional in-place density tests at locations where test maximum density samples were not taken. In these cases use the average of the three nearest test maximum densities that are representative of the material under consideration to calculate percent relative compaction.

REFERENCES

Test Methods Nos. Calif. 201, 216, 226, 231 and 905
End of Text on Calif. 312-E

